LIGHTNING DETECTION AND LOCATING SYSTEMS

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Introduction

In September 1983, the Office of Inspector General (OIG), Office of Audits (OA), Denver Regional Office (DRO), and the United States Department of Commerce (DOC), published a management audit report entitled, "Thunderstorm Killers – Flash Floods and Lightning, Need to Improve Severe Weather Forecasting." The purpose of the review was stated to evaluate National Weather Service (NWS) severe weather forecasting and to determine possible improvements in forecasting life-threatening severe weather, especially flash floods and lightning. The report briefly reviewed the historical development of severe storm forecasting, reviews loss-of-life statistics due to severe weather, and concludes that lightning has killed more people from 1940 through 1981 than tornadoes and hurricanes combined. Specific conclusions and recommendations were provided which are directed toward improving the national capability in providing public warnings of flash flood and lightning.

Federal agencies have pointed out that there are several coordinating mechanisms at work regarding the overall lightning issue. They also agree that improved coordination among agencies operating lightning detection systems might be mutually advantageous. As a result of this stimulus and general agreement among concerned agencies, there was a positive response to a request from DOC members of the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) for preparation of a report on present and planned lightning detection systems by the Office of the Federal Coordinator for Meteorology (OFCM).

A report is being prepared under the guidance of the OFCM for containing information outlining the present and planned lightning detection capability in all agencies and discusses opportunities for data sharing and cooperation.

Agency and Other Programs

Interest in lightning and lightning detection is evident in the programs of the governmental agencies, academia, industry (such as power companies), and the general public as served by TV stations. Each has particular interests and objectives. The following is a brief summary of these interests and programs of government agencies.

Summary of Agency Programs:

- The Western United States and Alaska are essentially covered by an operational lightning detection network operated and maintained by the Department of Interior, Bureau of Land Management (BLM). "Real-time" data are provided to other agencies.

- The Eastern United States has a research network operated by the State University of New York (SUNY) at Albany, New York. It is an expanding network funded by the National Science Foundation (NSF), by SUNY and partially by private industry and other government agencies. Data are made available to government and industry by special arrangement with SUNY.

- The Department of Defense, U. S. Navy (DOD/USN), either has or is planning significant activities covering the Eastern and Central U. S. These facilities are operated at present as local use facilities and are not in a network configuration.

- Other lightning detection facilities exist in the East Central U. S. which are not part of network configurations. Incorporating these facilities into existing or planned networks will require communications (ground or satellite) and data processors.

- Detection facilities are of two basically differing techniques: time of arrival and magnetic field direction finders (DF), and controversy remains concerning the relative capability of each. Thus the facilities are not compatible, but the data from each can be accommodated in a data distribution system which would accept processed data from the different detection networks.

- The SUNY network (currently characterized as an R&D network), if included as a part of a national network, would require some organizational and funding arrangements to accommodate the commitments already made by SUNY and to assure availability of the system as part of an operational network.

- Currently, there are no federal standards within which the existing systems must operate. Use of differing systems raises questions of relative accuracies, false alarm rate, etc. Procedural instructions of standards will most certainly be required in a network configuration.

- There are no well-established arrangements for archiving operational data from existing or planned networks. The Department of Interior (BLM)

has initiated an arrangement and agreement with the other agencies (Department of Agriculture, Forest Service, and possibly others) at its facility in Boise, Idaho.

- In some cases, funding of lightning detection research or operations by agencies is part of larger funded programs and are not identifiable as uniquely funded programs.

Sensor System Descriptions

Several lightning detection sensor designs have been developed in recent years which are the basis for lightning (sferics) detection systems. The three most prevalent of these design approaches are:

1. The magnetic direction finding equipment developed by Krider and now manufactured by Lightning Location and Protection, Inc. (LLP), which utilizes the angle-of-arrival approach;

2. A time-of-arrival (TOA) system developed by Bent and manufactured by Atlantic Scientific Corporation;

3. A satellite-borne lightning imager consisting of a fast lens telescope, a narrow band interference filter, and a focal plane photon detector developed by NASA.

Although systems for the detection and tracking of lightning bolts have been around since the days of Ben Franklin, modern techniques use one of these basic sensor designs.

The physical mechanisms upon which the generation of lightning is based are not universally agreed upon; however, it is generally accepted that lightning is a thermodynamic process within a cloud resulting in a big spark generator. This process sets the stage for cloud-to-ground, cloud-to-cloud, and intracloud discharges.

The ground-based lightning detection systems now being implemented are designed for the detection of cloud-to-ground discharges. Except for the Ryan Storm Scope, these systems take pains to filter out intra-/intercloud discharges between storm cells.

Cloud-to-ground discharges occur when the cloud potential reaches a level near breakdown and a leader or spark is generated between the cloud and earth. The leader creates an ionized trail which, when it reaches striking distance to Earth, results in the main stroke of approximately $200K$ amperes from earth to the cloud following the ionized trail left by the leader. Four or five return strokes approximately 10 microseconds in duration occur for each leader within a few milliseconds. These strokes generate an Electromagnetic Pulse (EMP) which radiates radio frequency (RF) energy or noise which is the signal detected by the sensors. Most of the energy is in the Very Low Frequency (VLF) 1 KHz band and is distributed at

decreasing amplitudes up through the Ultra High Frequency (UHF) 10 GHz band.

A similar mechanism occurs for intra-/intercloud discharges between cells within a cloud and for cloud-to-cloud discharges. The EMP intensities of these discharges are a fraction of the cloud-to-ground discharge. Even so, the electromagnetic fields generated by the discharges can induce potentials in power and signal lines which have disastrous effects.

The magnetic direction finding equipment senses the electromagnetic fields of the lightning using two orthogonal magnetic loop antennas and a flat plate electric field antenna. A wide bandwidth (1 MHz) receiver is used to preserve the shape of the pulse. The system is designed to respond only to the waveshape characteristic of the cloud-to-ground flashes. This equipment outputs the angle with respect to north of the observed EMP. The system manufactured by LLP consists of two or more gated, wideband magnetic DF stations that are separated by tens-to-hundreds of kilometers and transmit lightning direction and signal amplitude data to a central position analyzing (PA) computer. When the PA receives two or more simultaneous inputs from the remote DF stations, it computes the location of the lightning source by either triangulation or the DF angle vectors (Figure 1).

The TOA equipment consists basically of two receivers, one to detect the lightning stroke and the other to detect the highly accurate LORAN timing source. The TOA equipment uses a VHF wideband receiver to detect the lightning and the LORAN C 100 KHz receives timing pulses for synchronization. The output of this equipment is the arrival time of a lightning pulse with respect to the LORAN C synchronization pulse. The system locates the source of the EMP by plotting the arrival time of the pulse from two or more receiving stations. As a result, the receiving equipment is quite simple.

Atlantic Scientific Corporation developed a system (LPATS) which uses three or more (usually four) TOA sensor stations all synchronized to the same LORAN C timing source. These stations are connected via dedicated communications circuits to a central analyzer facility which measures the difference in the times of arrival from the geographical dispersed sensors and determines the location of the lightning using hyperbola triangulation (Figure 2). Tests using TOA systems were conducted by the Air Force Wright Aeronautical Laboratories (AFWAL) in 1979, 1980, and 1981.

The Ryan Storm Scope is an airborne, or may be ground-based, lightning detection system which uses the magnetic direction finding crossed loop and sense antenna sensor to detect the range and azimuth of lightning discharges. Azimuth is determined from the ratio of the two crossed loop antenna inputs. Range is determined by measuring the field strength of the lightning discharge with respect

to a constant. The constant is derived from an assumption that the field strength is relatively constant from discharge to discharge and inversely proportional to the square of the range. A CRT readout with memory provides a plan position display of the lightning strikes. There are about 7,000 storm scopes installed and in use as an in-flight weather avoidance and lightning detection system.

The AFWAL tested the system in the summer of 1981. The results of the tests are contained in AFSC Report AFWAL-TR-83-3083. Basically, they concluded that the storm scope shows reasonable accuracy in azimuth and fairly large inaccuracies (+ or - 25 miles) in range.

The Ryan Storm Scope Company has been acquired by the 3M Company. The 3M Company has incorporated several improvements in the Ryan Storm Scope and now markets it as a 3M product.

NASA has developed a lightning imaging system for installation on a GOES-type satellite which will detect and locate lightning over large areas of the earth. The system has not been implemented and is expected to require additional refinement because of the strong background noise produced by sunlight reflection from tops of clouds.

Implementation of any of these systems should consider:

1. Overall agency requirements

2. Communications costs. A high-quality dedicated duplex telephone circuit costs about $12,000 per year for each PA

3. Detection and tracking of both intra- and intercloud lightning

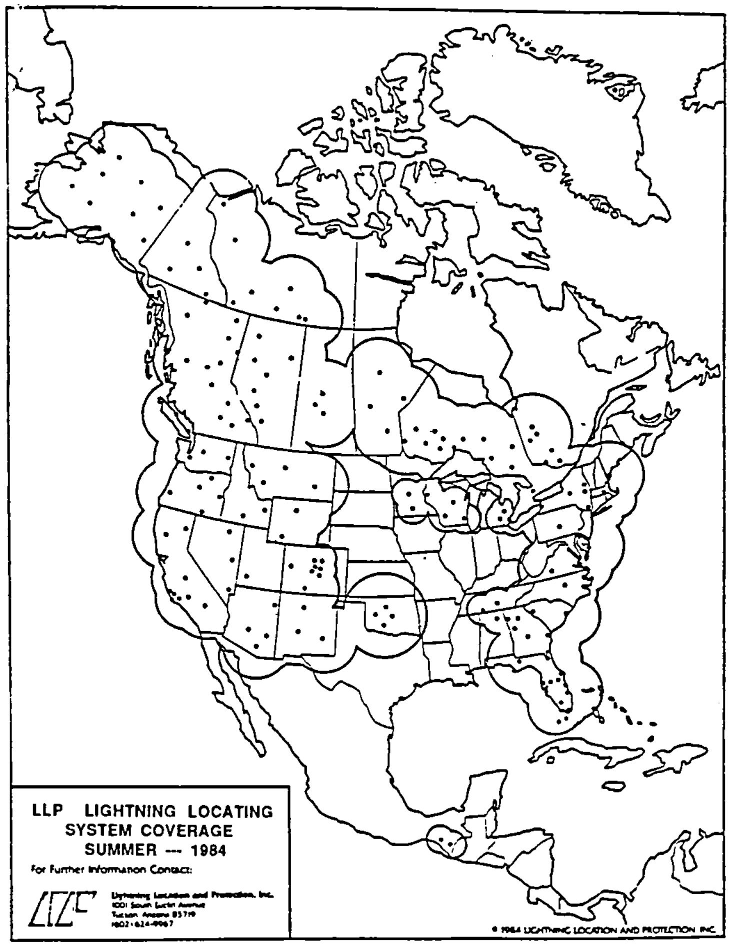

Figure 1. LLP Lightning Locating System Coverage, Summer 1984.

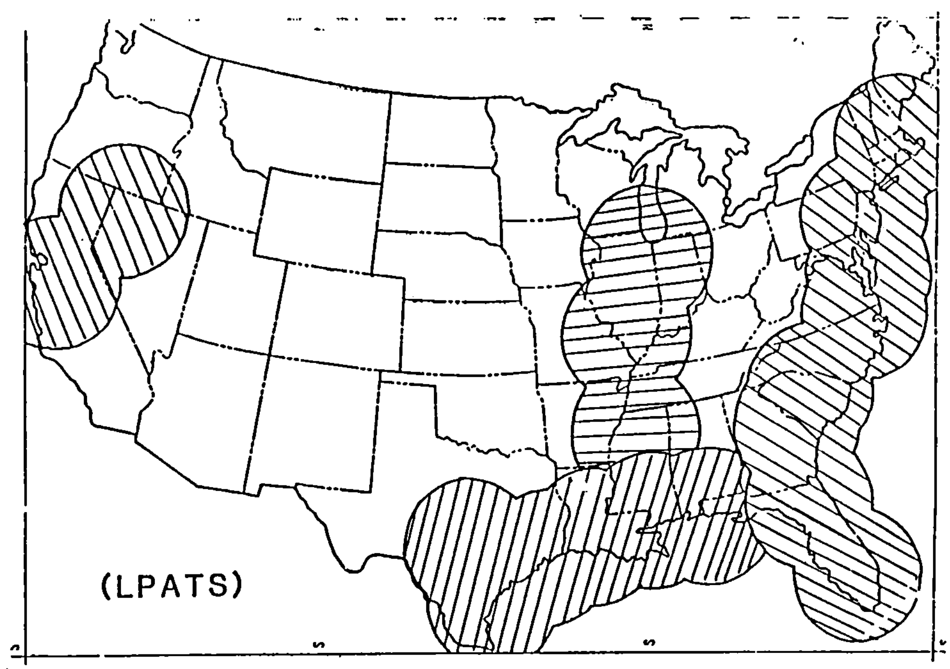

Figure 2. Lightning Position and Tracking System.